Advanced LIGO overview and update

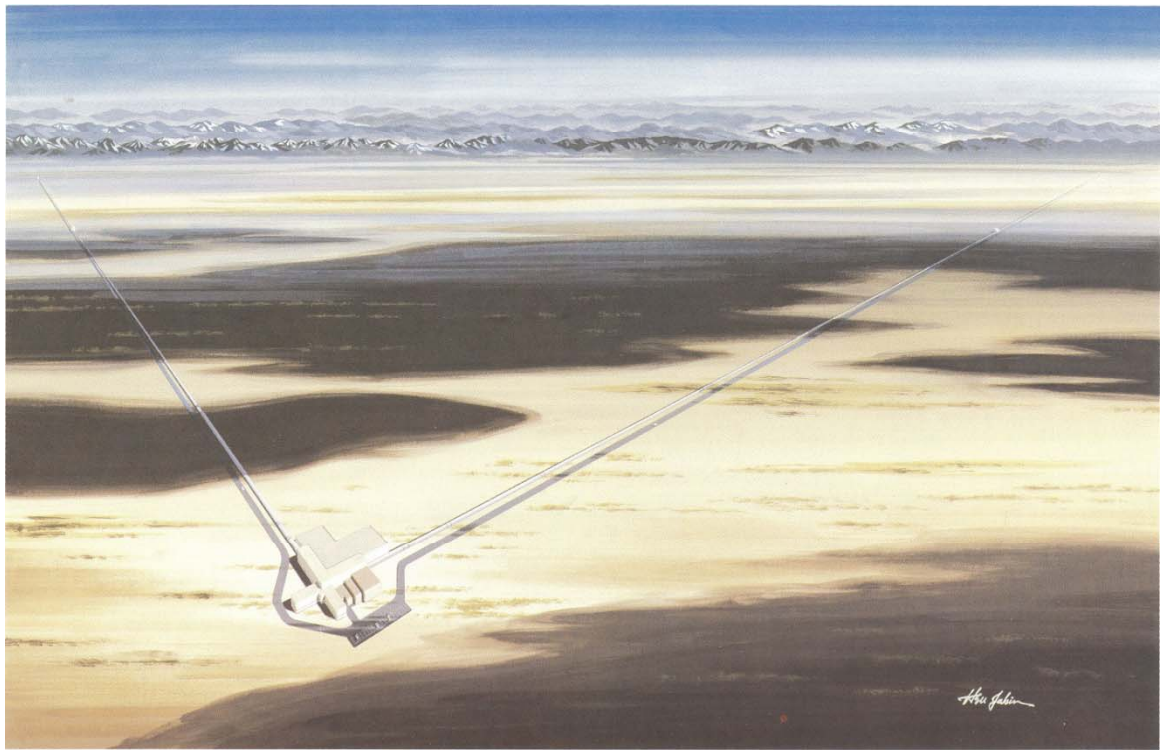
David Shoemaker
Advanced LIGO Project Leader

LIGO: 1989 Proposal to the National Science Foundation

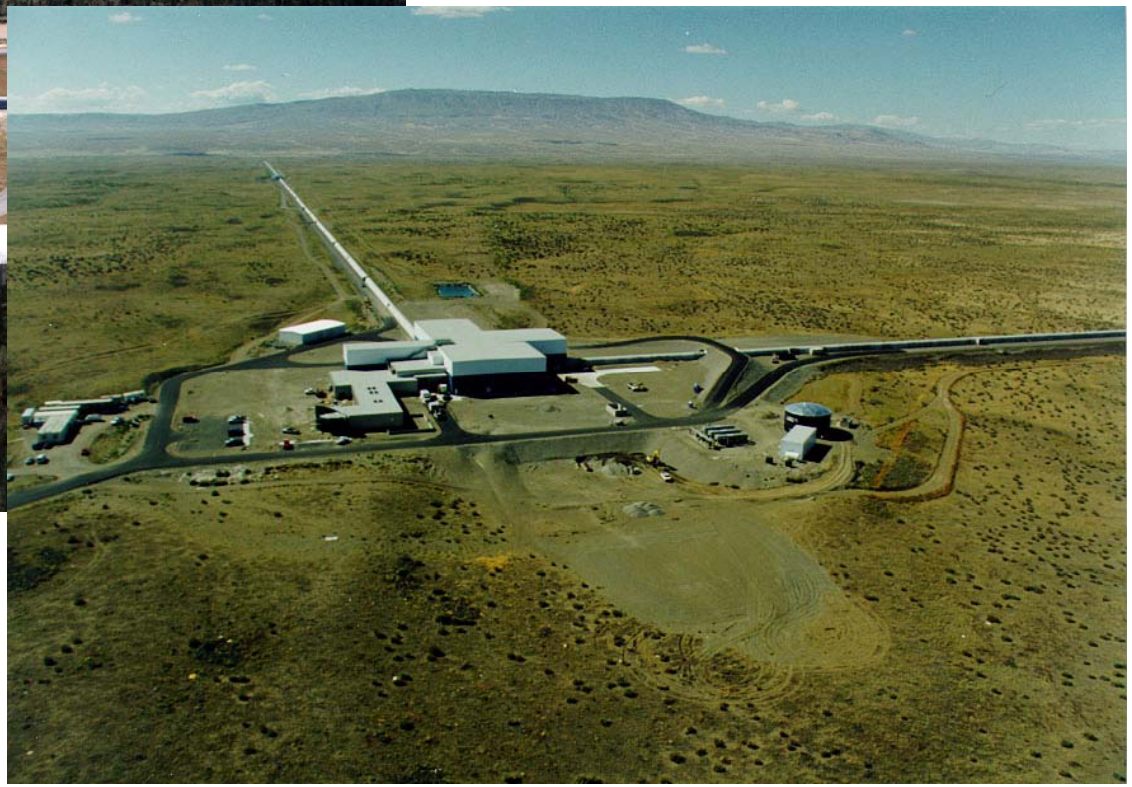
PREFACE

This proposal requests support for the design and construction of a novel scientific facility—a gravitational-wave observatory—that will open a new observational window on the universe.

The scale of this endeavor is indicated by the frontispiece illustration, which shows a perspective of one of the two proposed detector installations. Each installation includes two arms, and each arm is 4 km in length.



Observatories and Initial LIGO constructed ~1994 - 2000



Thanks, NSF

What and why?

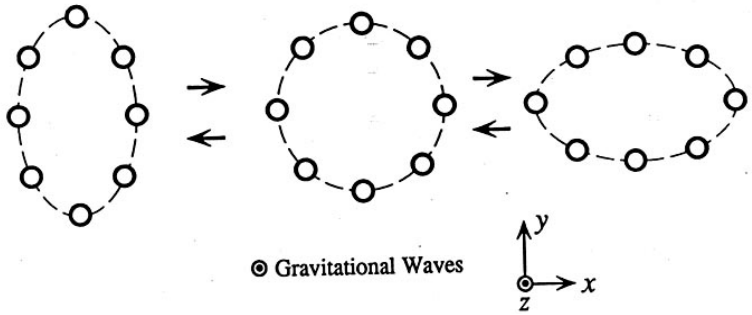
- Gravitational waves are ripples in space-time – stretching and compressing space itself
- A good source: two stars orbiting around each other near the speed of light (a ‘neutron star binary’)
- Signal carries information about **very** extreme conditions of matter, space, and gravitation

- It’s a brand new way of seeing the Universe

- Will help to understand black holes and other exotic phenomena
- Will be used with other astronomical tools – Optical and radio telescopes, neutrino and gamma ray detectors – to build a more complete picture of what’s out there

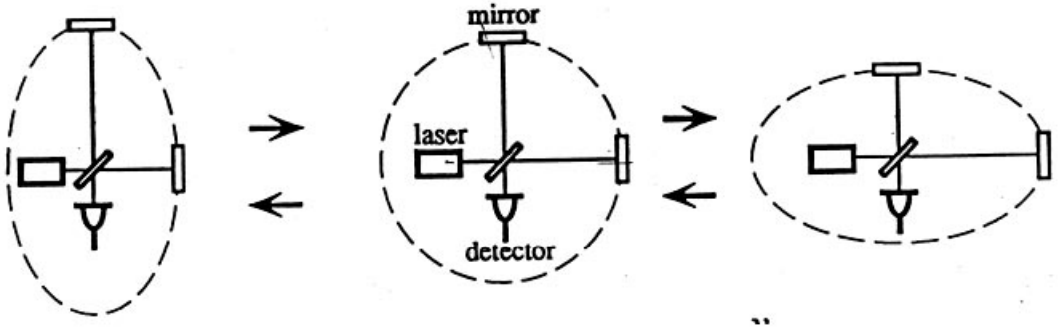
Credit: T. Strohmayer and D. Berry

How to detect them?



Passing wave distorts space – changes distances along vertical and horizontal paths

Michelson interferometers can measure these distortions by comparing light along two arms at right angles



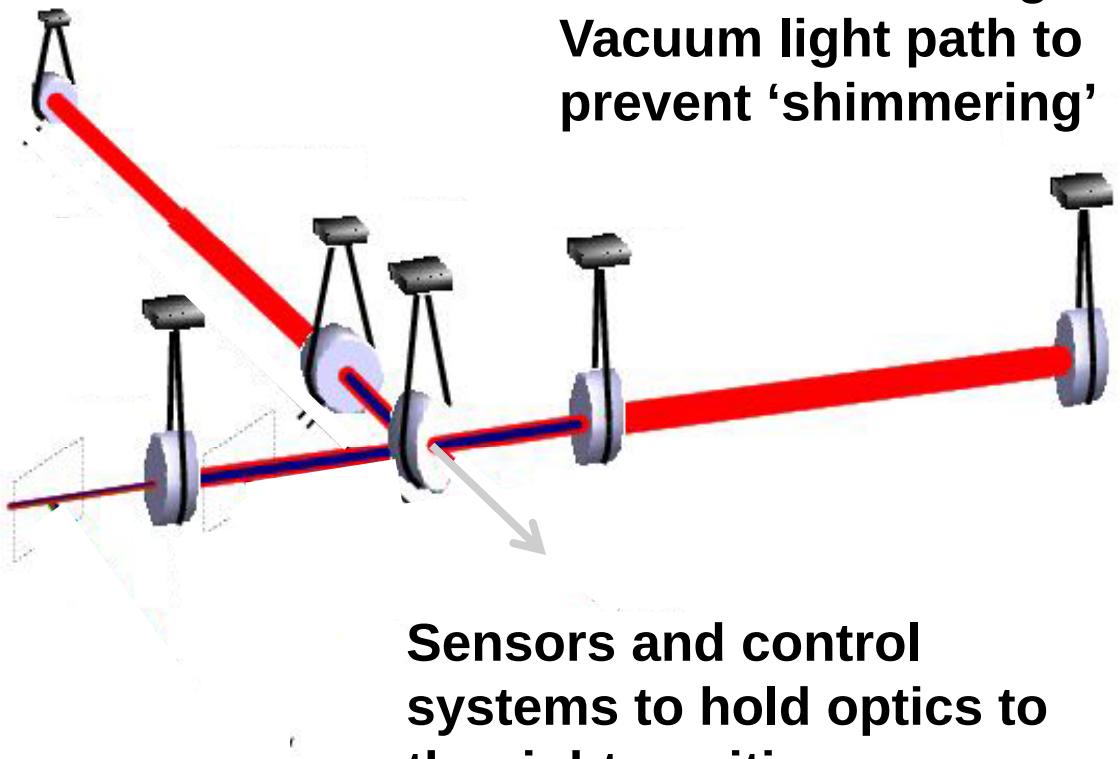
Longer arms → bigger signals (like radio waves), but still very very small length changes:
0.00000000000000001 inch (ouch)
over 2.5 miles for the strongest sources
-- a strain sensitivity of one part in 10^{21}

The LIGO Detectors: a bit more detail

Seismic isolation and Suspension to ensure that only GWs move the test masses

Superb optics to minimize light loss

4km arms for a larger signal
Vacuum light path to prevent 'shimmering'



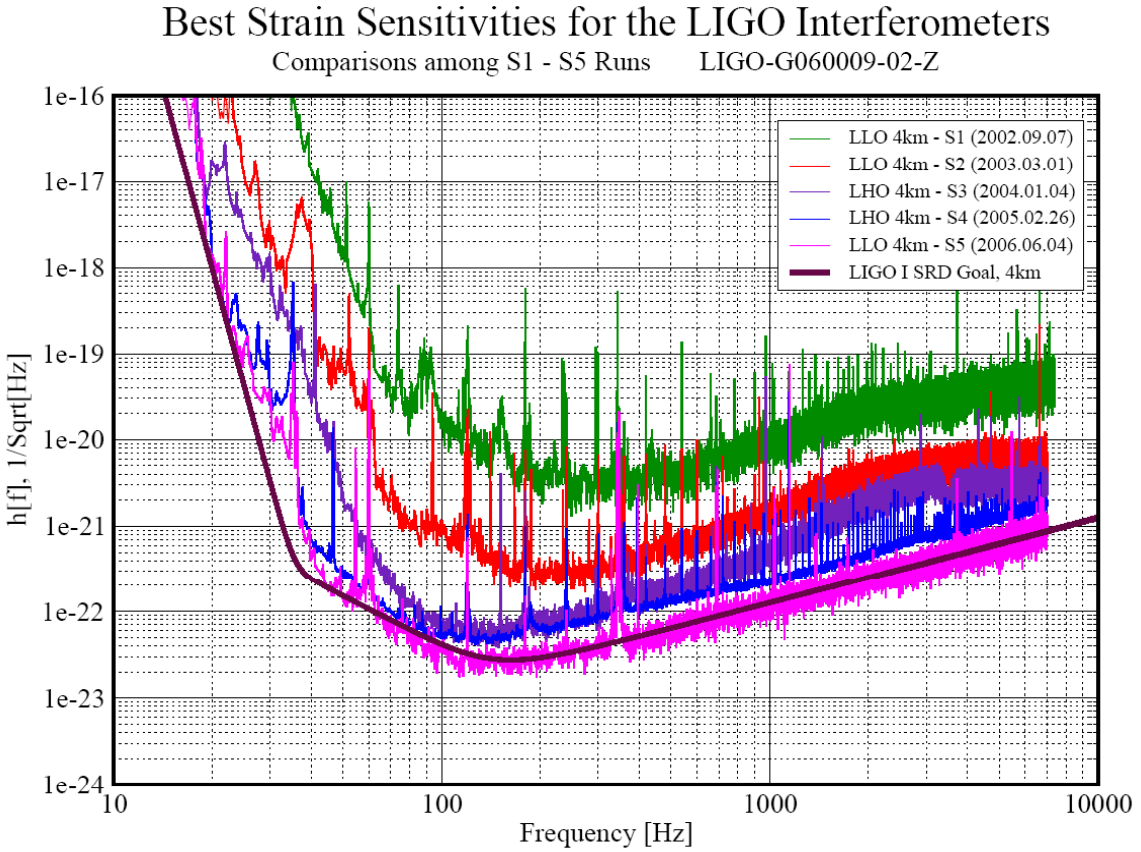
Powerful, stable laser to make distance measurement precise

Laser

Sensors and control systems to hold optics to the right position

A bit more history

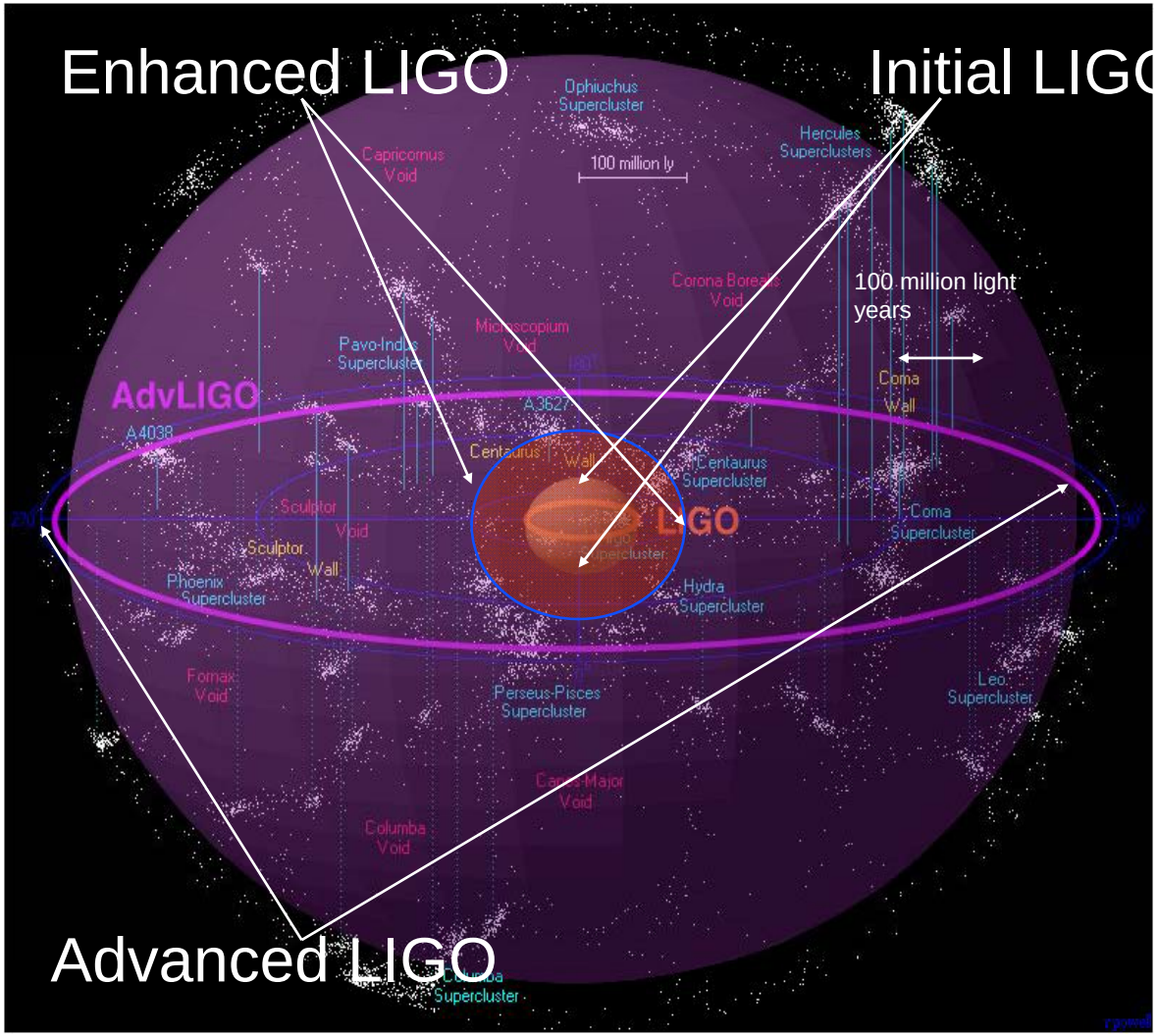
- Initial LIGO worked, to everyone's astonishment!
- Plot shows improvement over time – reached the (solid black) goal
- ..but no signals detected *so far*
- Enhancements installed in 2009
  - » Now searching with this improved instrument
  - » Let's hope for a signal!



- But: **Time for a really significant step forward.**

Advanced LIGO

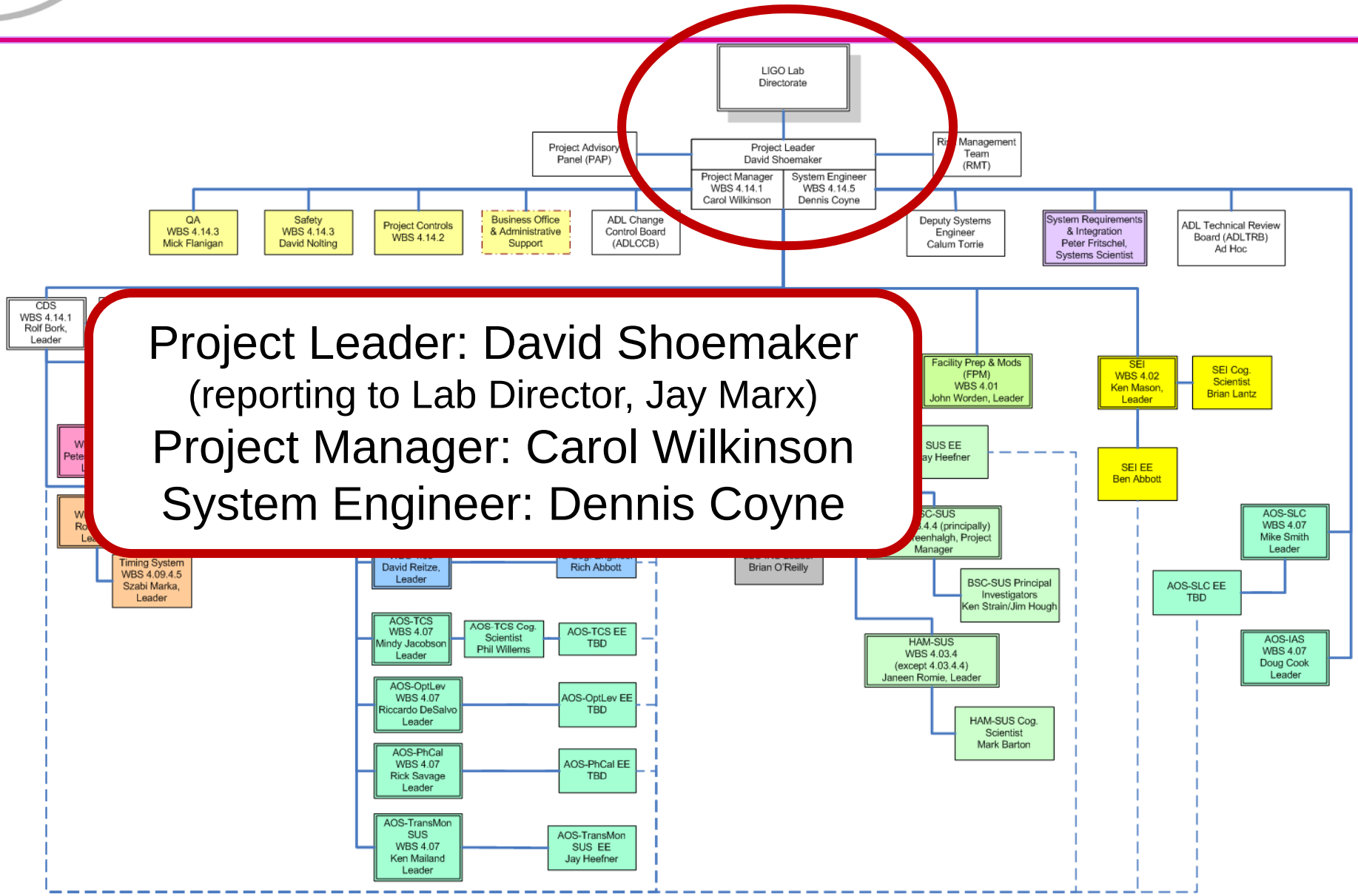
- Factor 10 improvement in sensitivity
- Better low frequency response
- More than 1000 times more sources within reach
- Signal predictions go from ~1 per 10 years (iLIGO) to ~**1 per week** (aLIGO)



Advanced LIGO: Big Picture

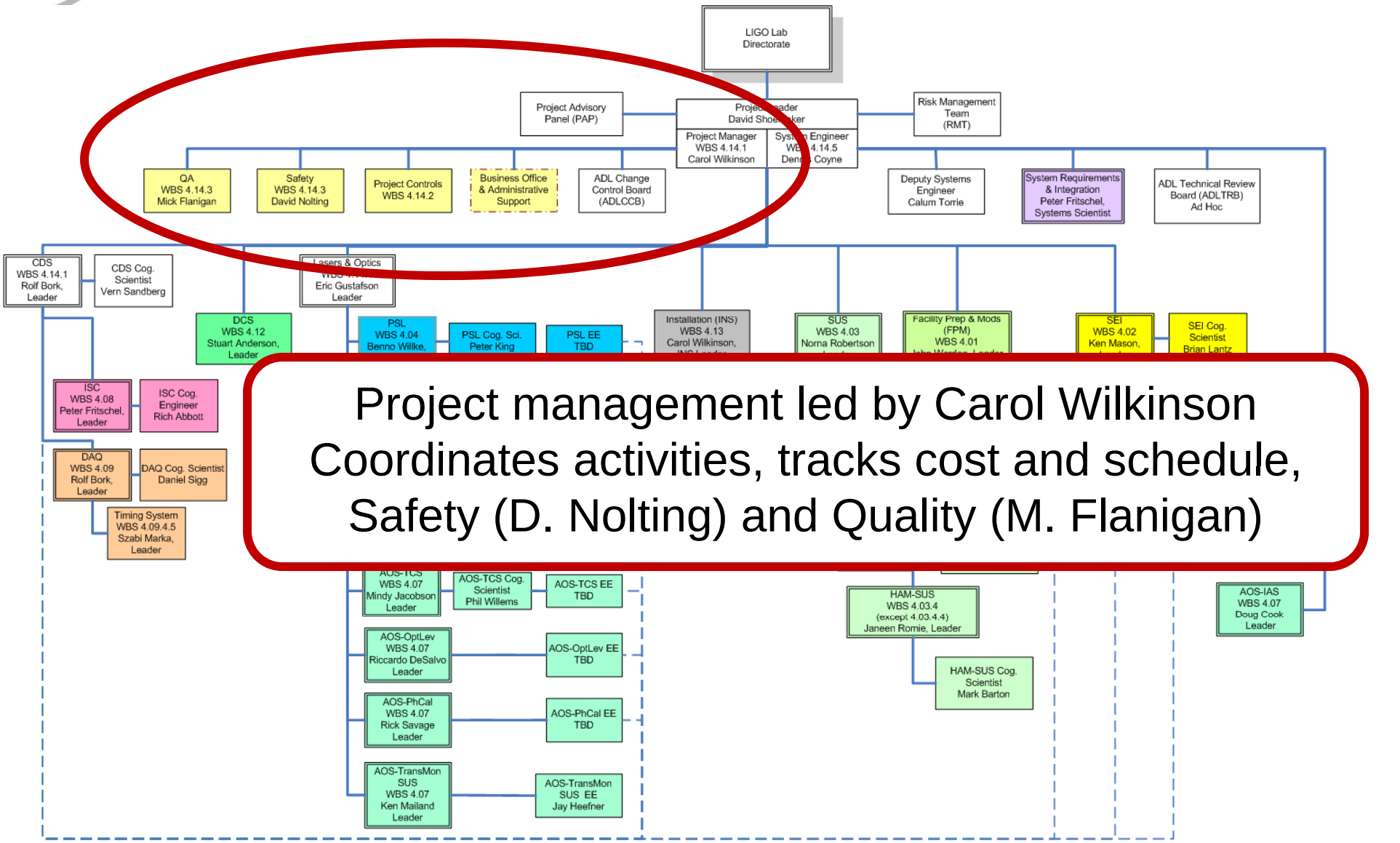
- Have been working on aLIGO designs since ~1999, just about finished
- Project started April 2008, wraps up in 2015
  - » Will observe with aLIGO for quite some time after that
- Enthusiastically supported by the National Science Foundation – truly a great government agency
- Costs $205 million from the NSF,
  plus contributions from UK, Germany, Australia
- Caltech and MIT are the responsible institutions
- Complete replacement of instruments at Livingston and Hanford
  - » Buildings, vacuum equipment reused

Advanced LIGO: organization



Project Leader: David Shoemaker
(reporting to Lab Director, Jay Marx)
Project Manager: Carol Wilkinson
System Engineer: Dennis Coyne

Advanced LIGO: organization

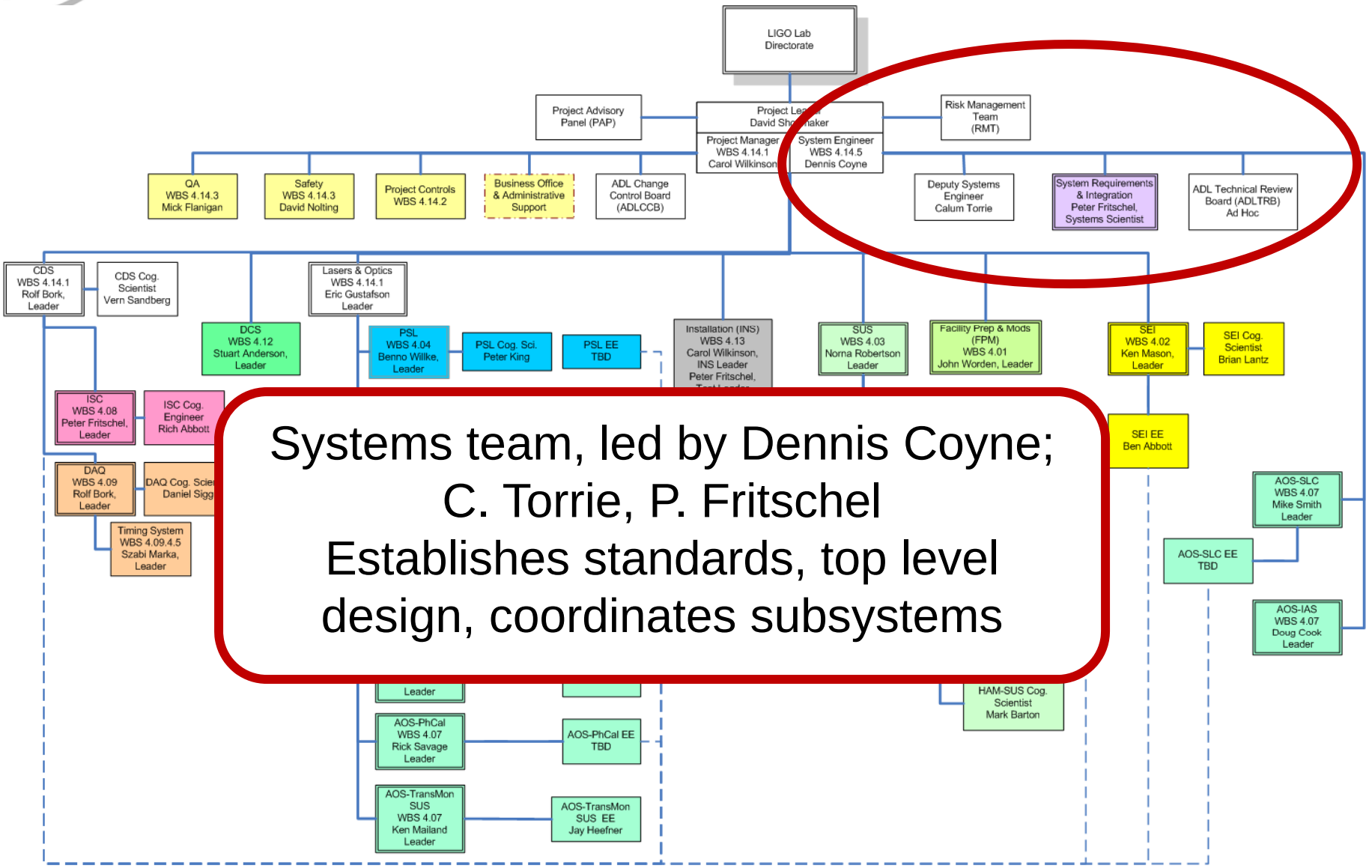


Project management led by Carol Wilkinson
Coordinates activities, tracks cost and schedule,
Safety (D. Nolting) and Quality (M. Flanigan)

Advanced LIGO Project Organization

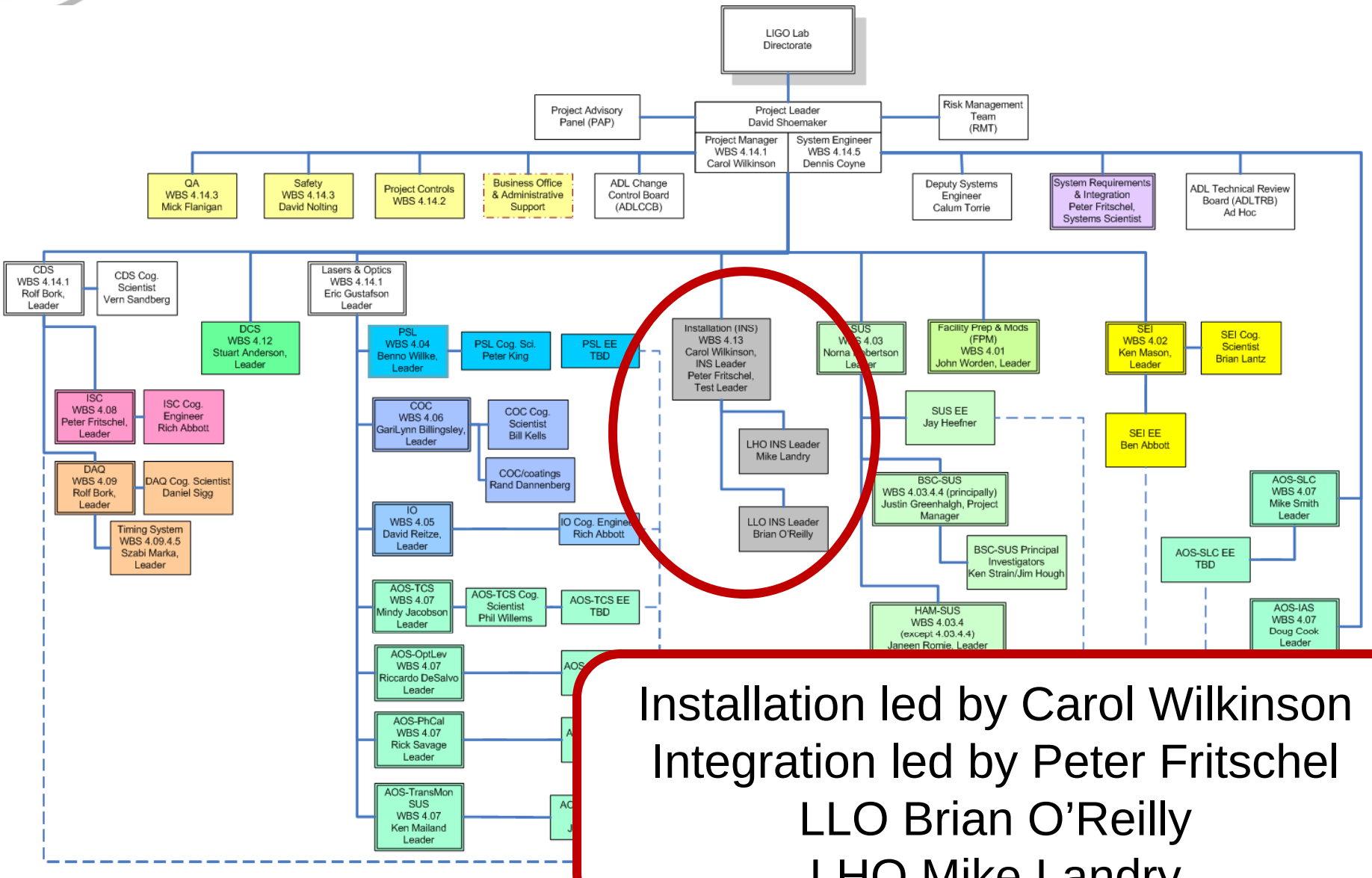
LIGO-M070069-v5
14 Jan 2010

Advanced LIGO: organization



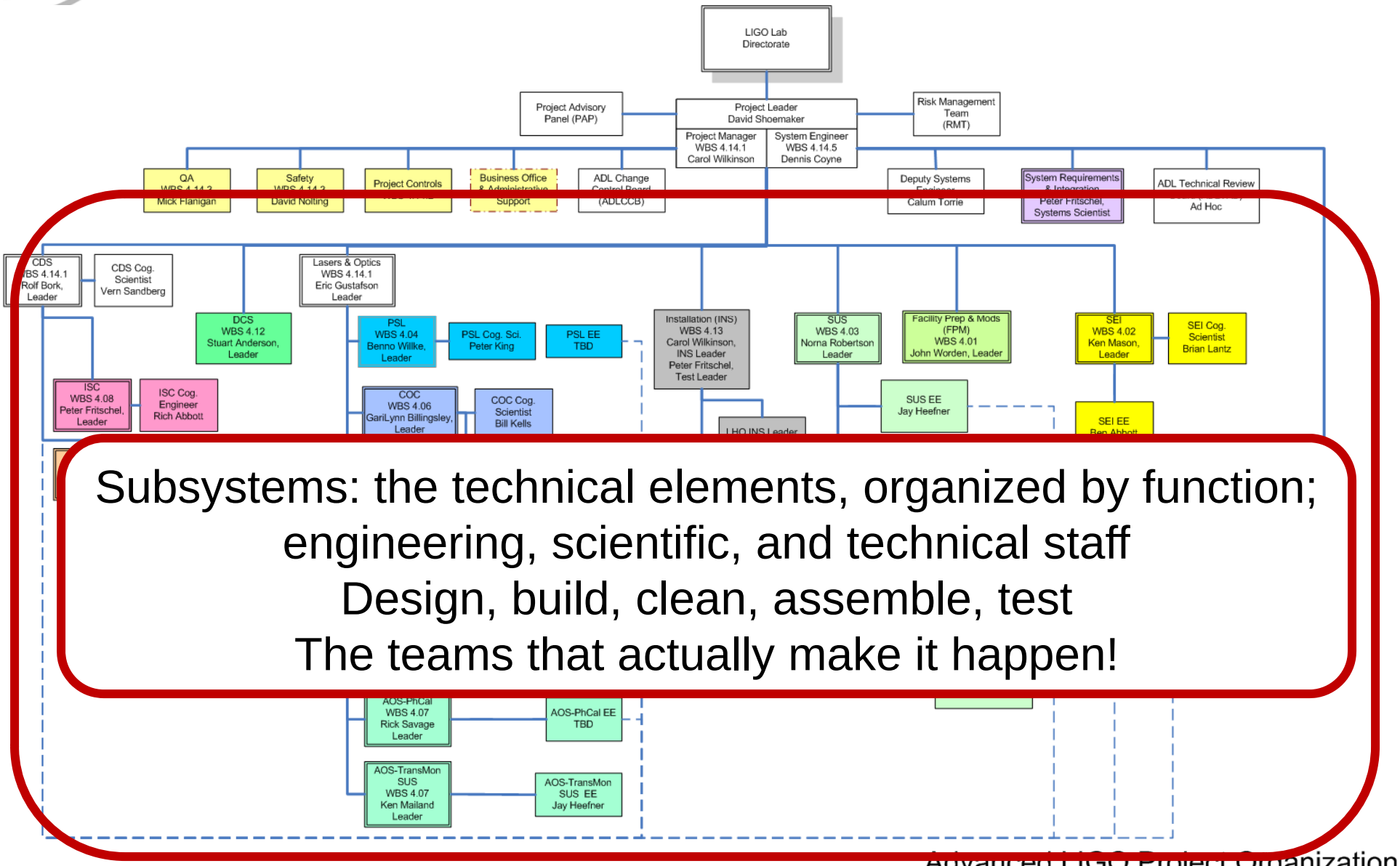
Systems team, led by Dennis Coyne;
C. Torrie, P. Fritschel
Establishes standards, top level design, coordinates subsystems

Advanced LIGO: organization



Installation led by Carol Wilkinson
Integration led by Peter Fritschel
LLO Brian O'Reilly
LHO Mike Landry

Advanced LIGO: organization



Subsystems: the technical elements, organized by function; engineering, scientific, and technical staff

Design, build, clean, assemble, test

The teams that actually make it happen!

What Stays: LIGO Beam Tube

- 1.2 m diameter stainless tubing, pumps only every 2 km

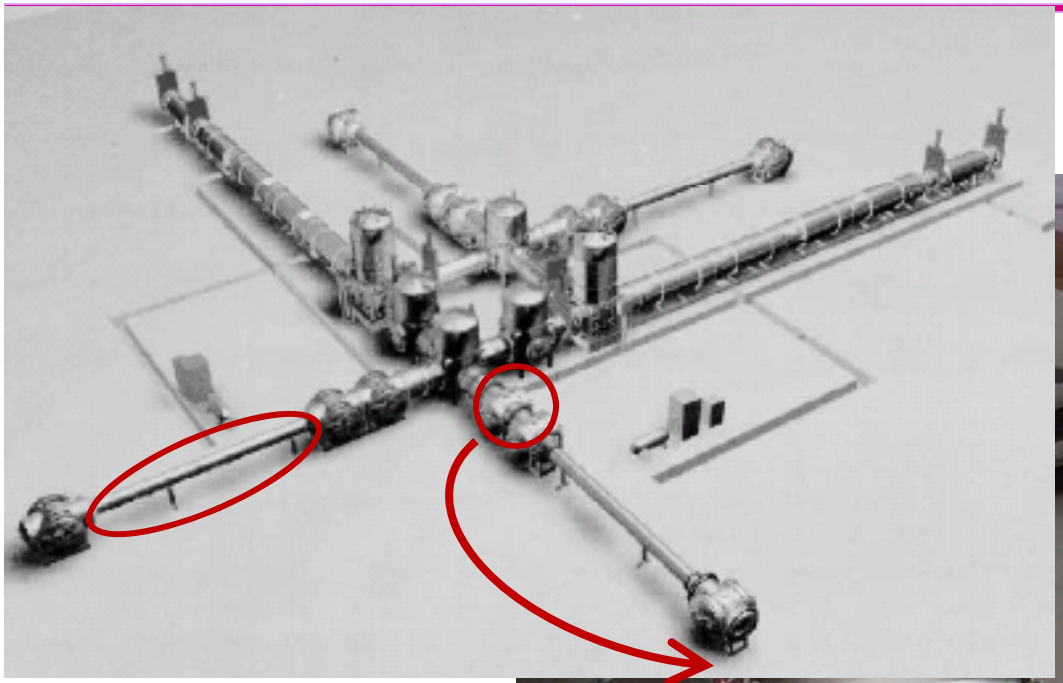
- Aligned to within mm over km (corrected for curvature of the earth)

- Total of 16km fabricated with no leaks

- Cover needed (stray bullets, stray cars…)

Small changes: Vacuum Equipment

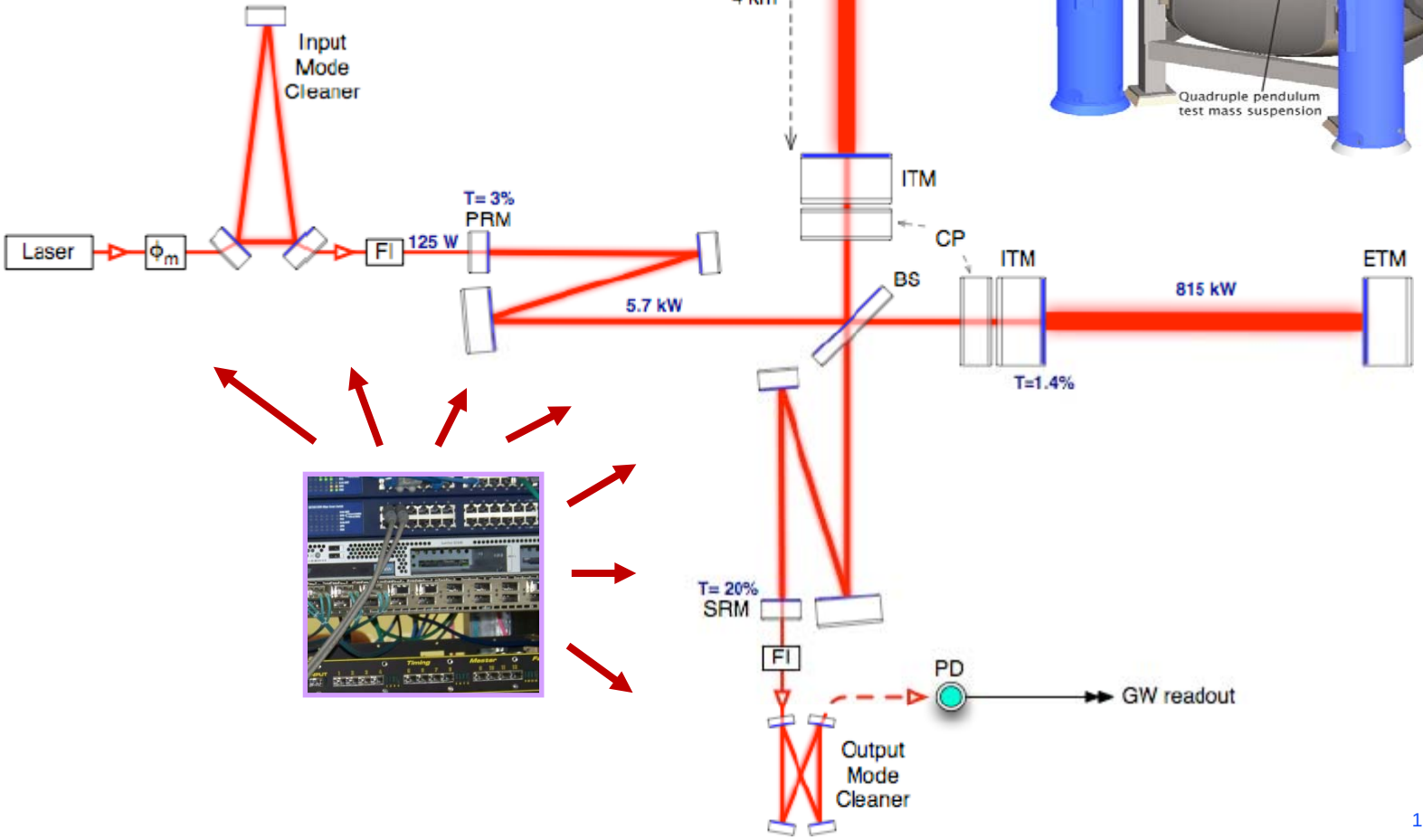
(some HAM chambers moved, larger connecting tubes, move LHO 2km BSC chambers to 4km point)

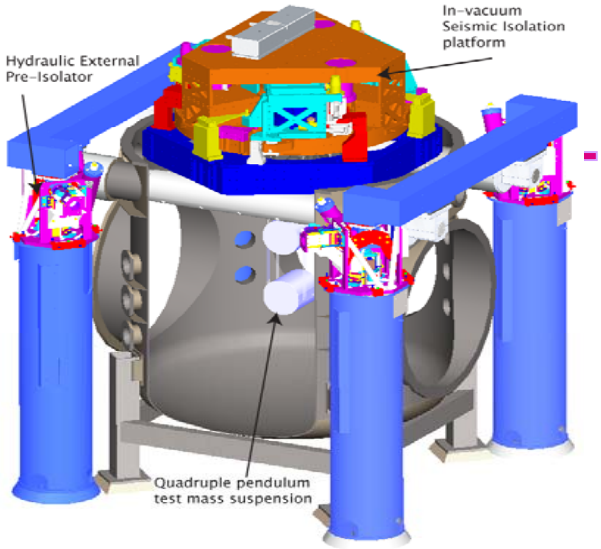


John Worden (LHO), Rusyl Wooley (LLO)

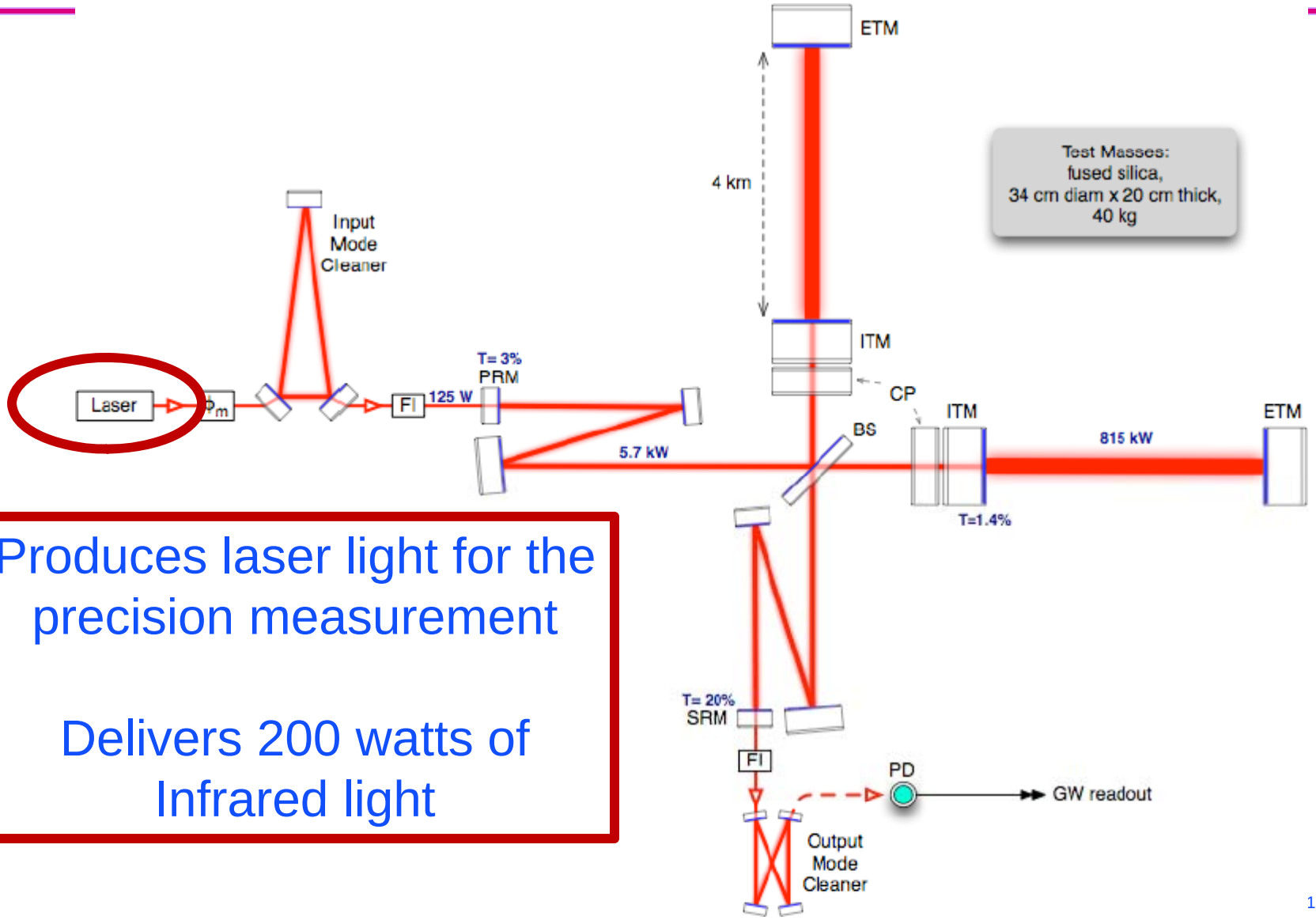
Also includes the clean rooms, baking, storage

What's replaced: everything else





Pre-Stabilized Laser (PSL)

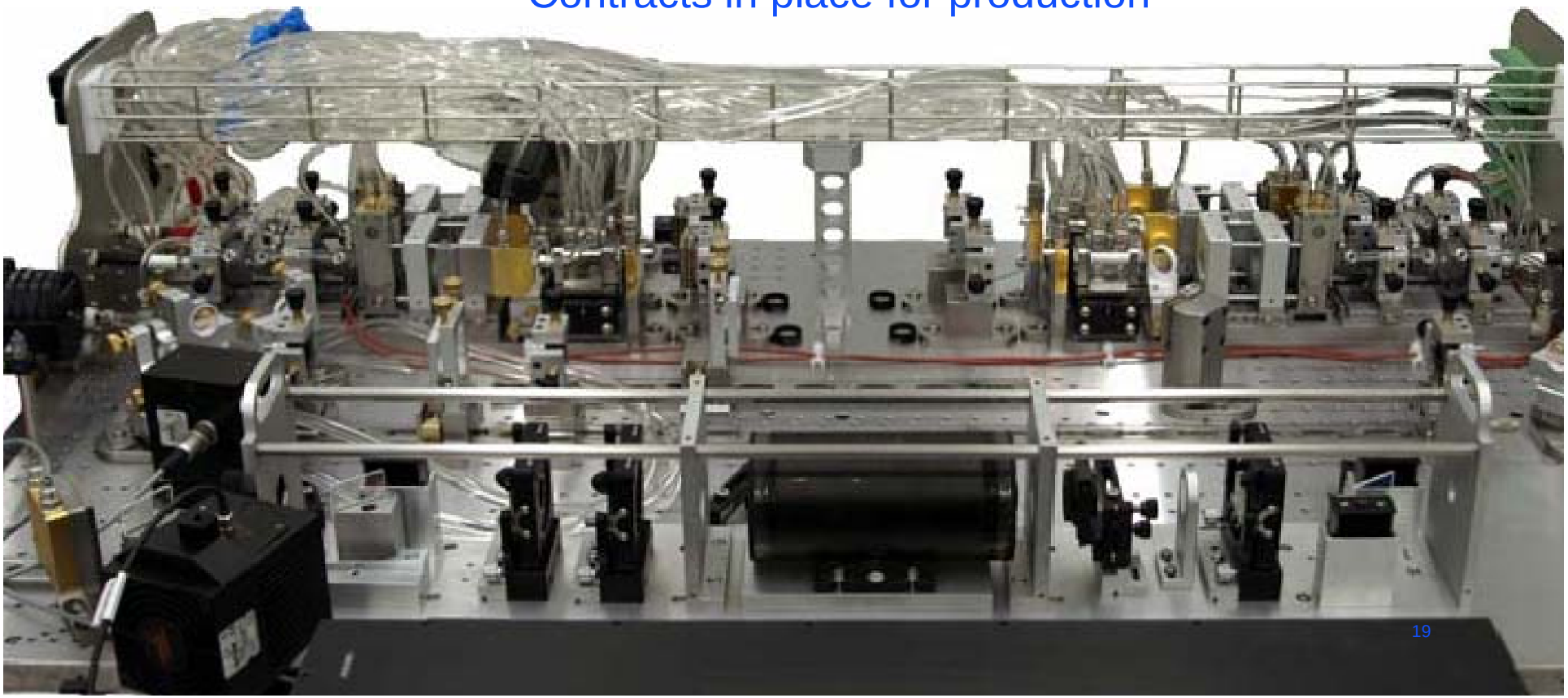


Produces laser light for the precision measurement

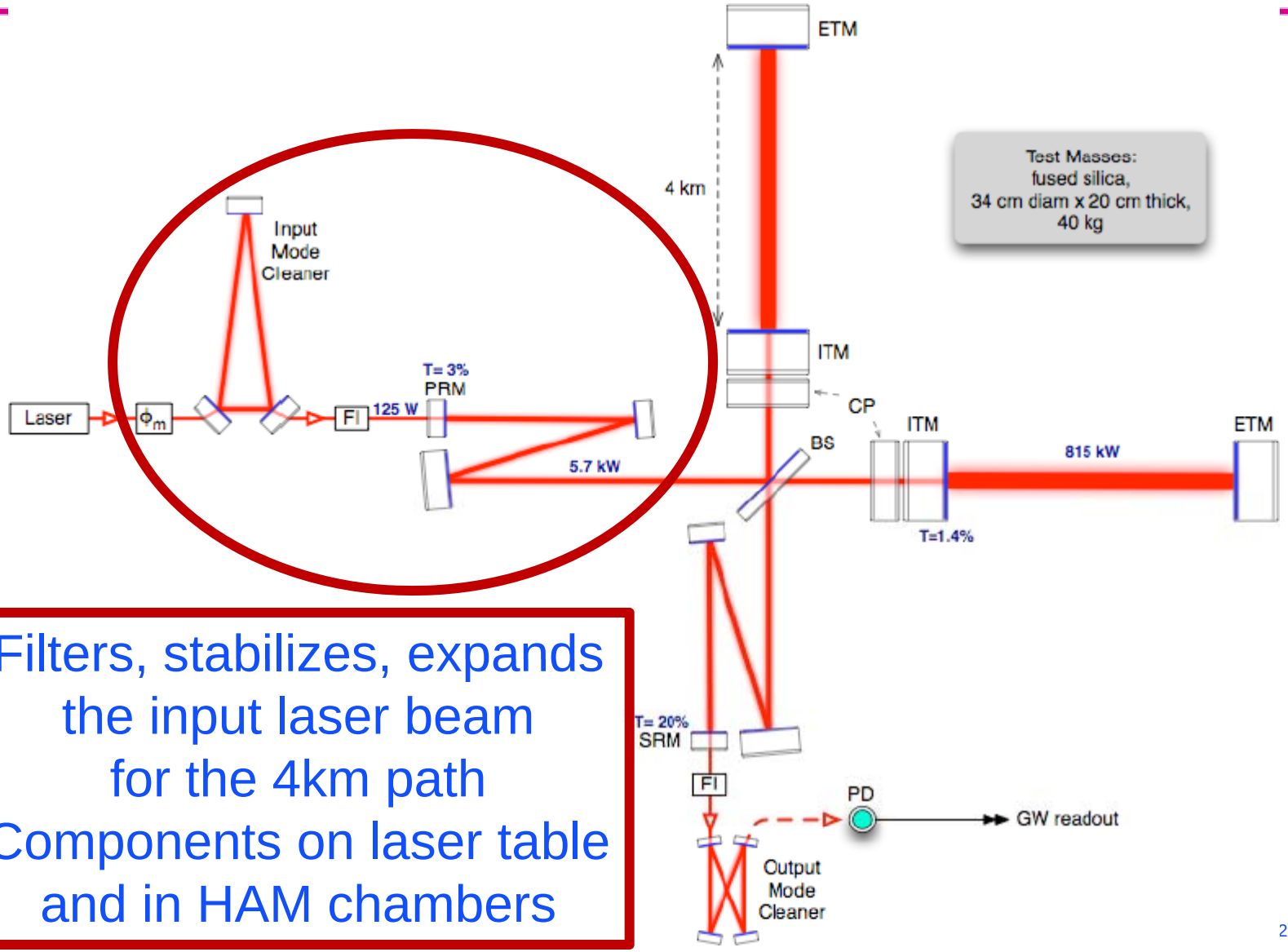
Delivers 200 watts of Infrared light

Pre-Stabilized Laser (PSL)

- Designed and contributed by AEI Max Planck, Hannover, Germany
  - » Benno Willke, Max Planck leader; Peter King, LIGO leader
  - » Enhanced LIGO lasers use the first stages of the system
    - Final design review this month
    - Contracts in place for production



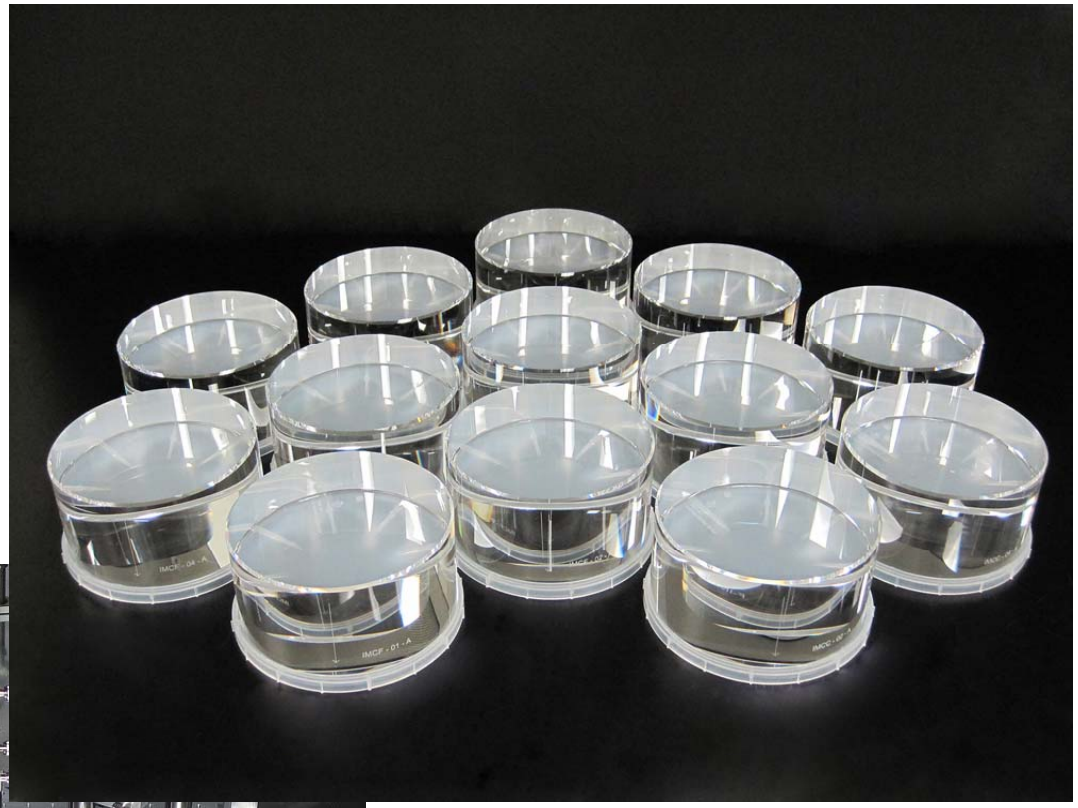
Input Optics (IO)



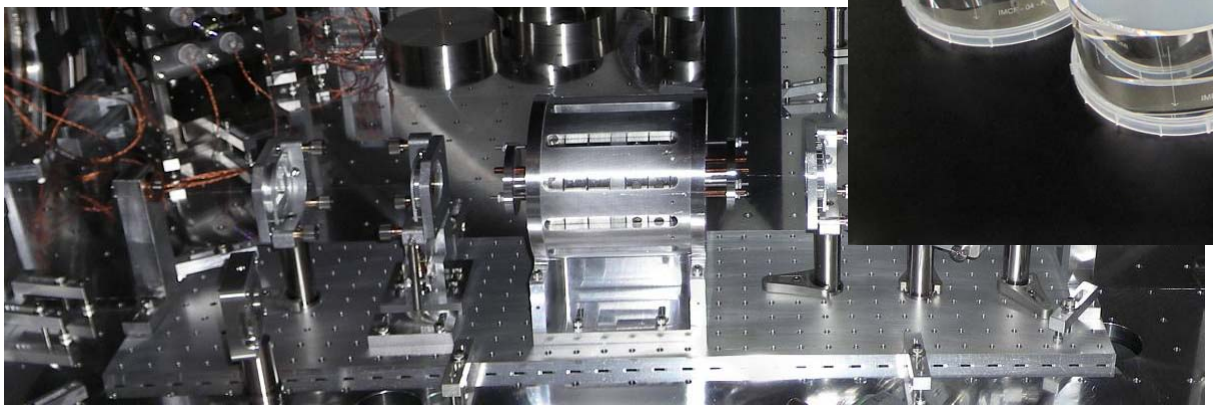
Filters, stabilizes, expands the input laser beam for the 4km path
Components on laser table and in HAM chambers

Input Optics (IO)

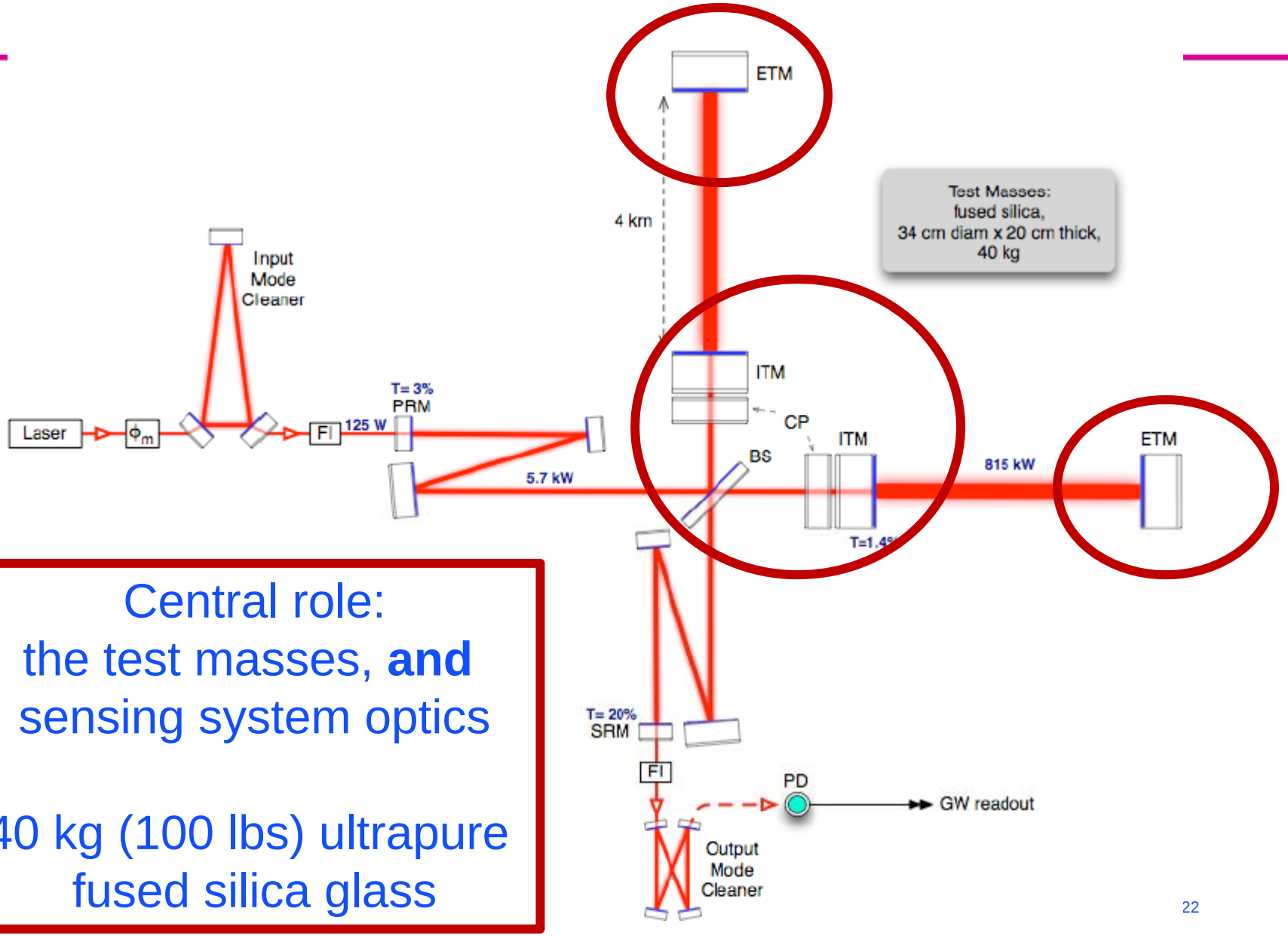
- Designed, built by the University of Florida team, Dave Reitze lead
- Includes modulators and optical isolators used in eLIGO
- Suspended optics (on SUS HAM Small and Large Triples)



- Final Design review just ending
- Optics in production



Core Optics Components (COC)

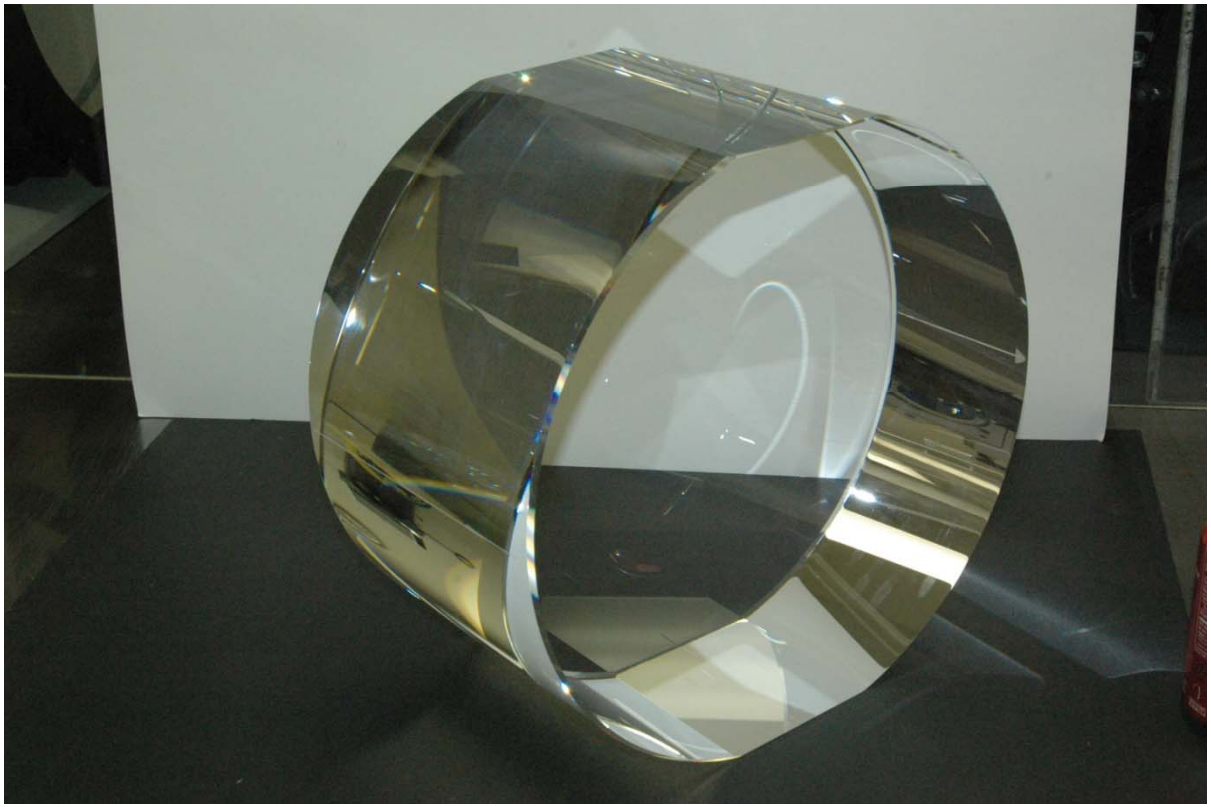


Central role:
the test masses, **and**
sensing system optics

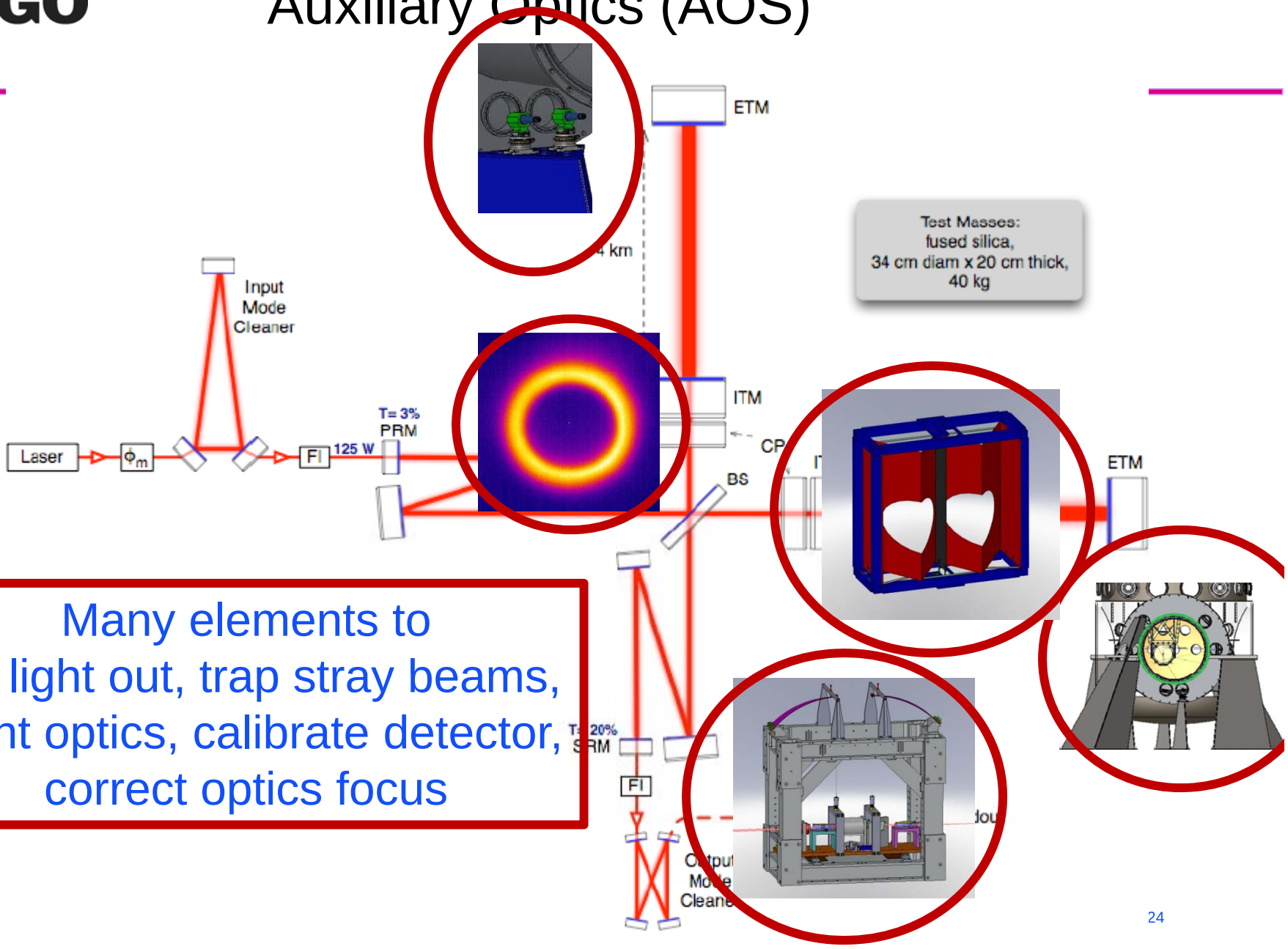
40 kg (100 lbs) ultrapure
fused silica glass

Core Optics Components (COC)

- Led by Garilynn Billingsley
- All substrates delivered
- Polishing underway
- Reflective Coating process starting up
- Measurement system on order



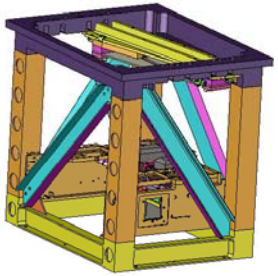
Auxiliary Optics (AOS)

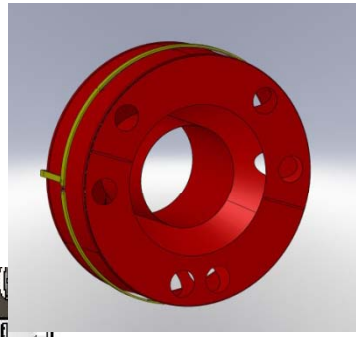


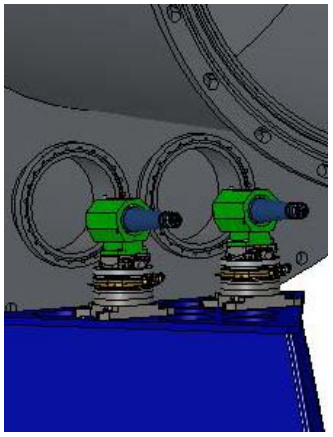
Many elements to
get light out, trap stray beams,
point optics, calibrate detector,
correct optics focus

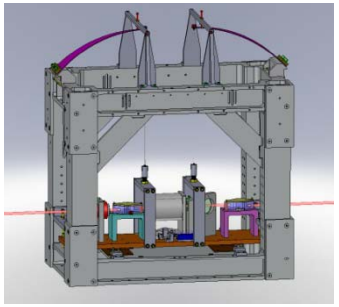
Auxiliary Optics (AOS)

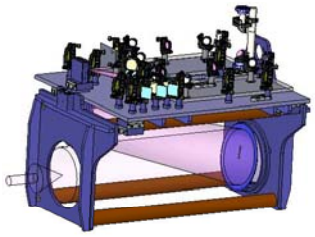
- Large (and growing!) team spread out; Eric Gustafson and Dennis Coyne coordinating
- Subsystem elements still in the design phase, with wrap-up over the coming year

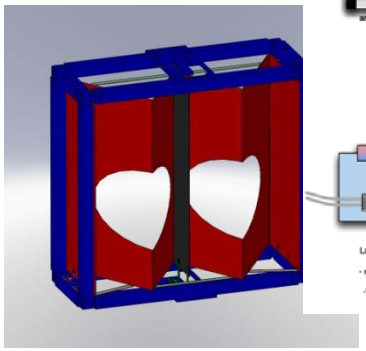




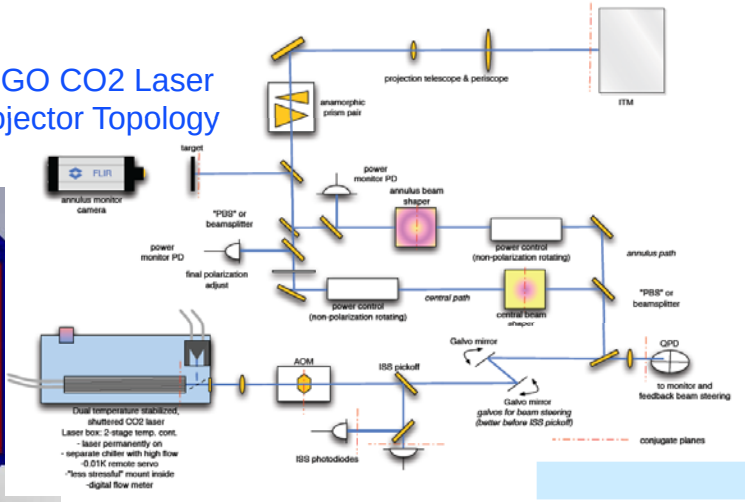




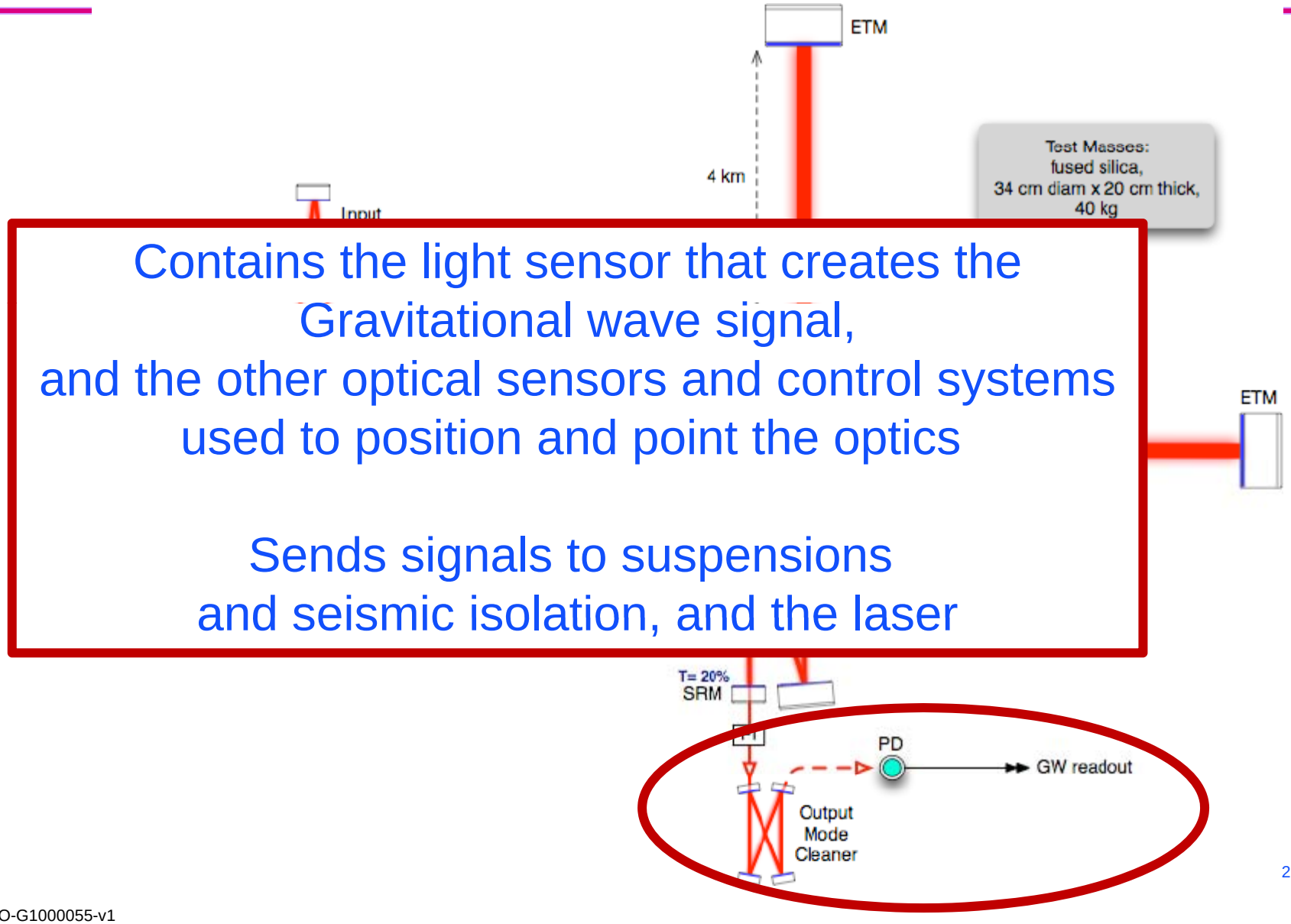




aLIGO CO2 Laser Projector Topology



Interferometer Sensing and Control (ISC)

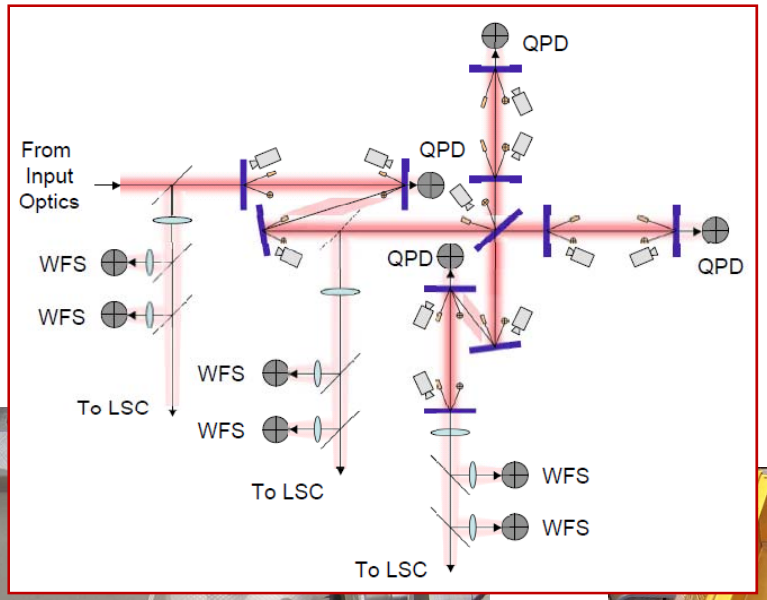


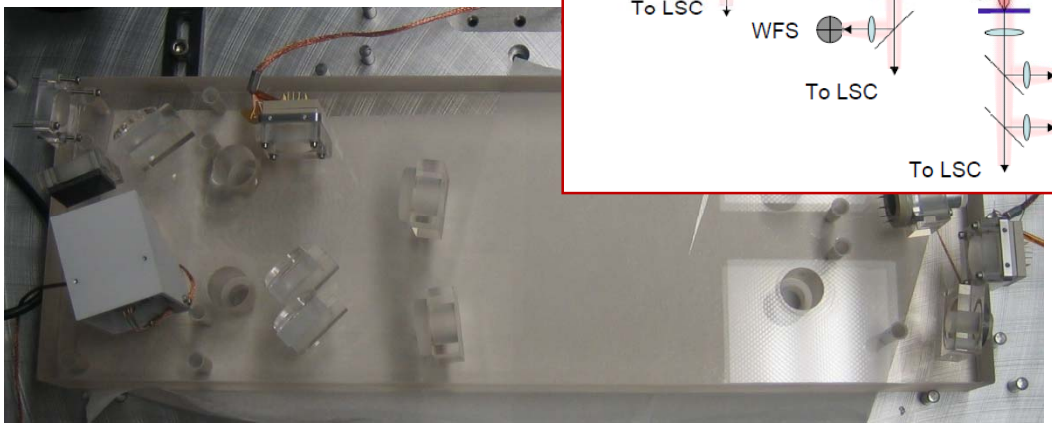
Contains the light sensor that creates the Gravitational wave signal,
and the other optical sensors and control systems used to position and point the optics

Sends signals to suspensions
and seismic isolation, and the laser

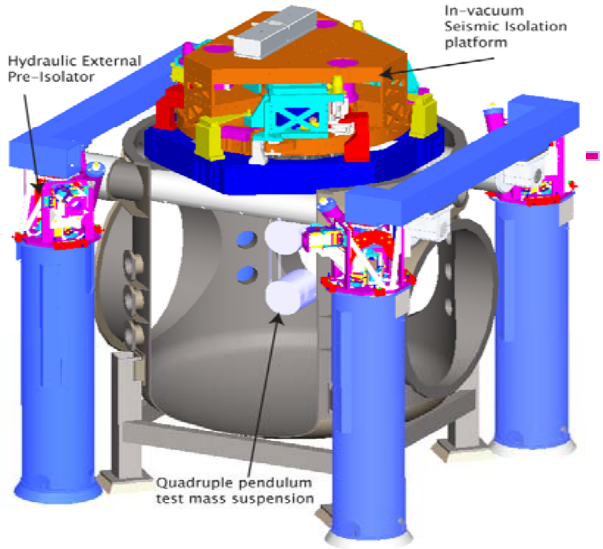
Interferometer Sensing and Control (ISC)

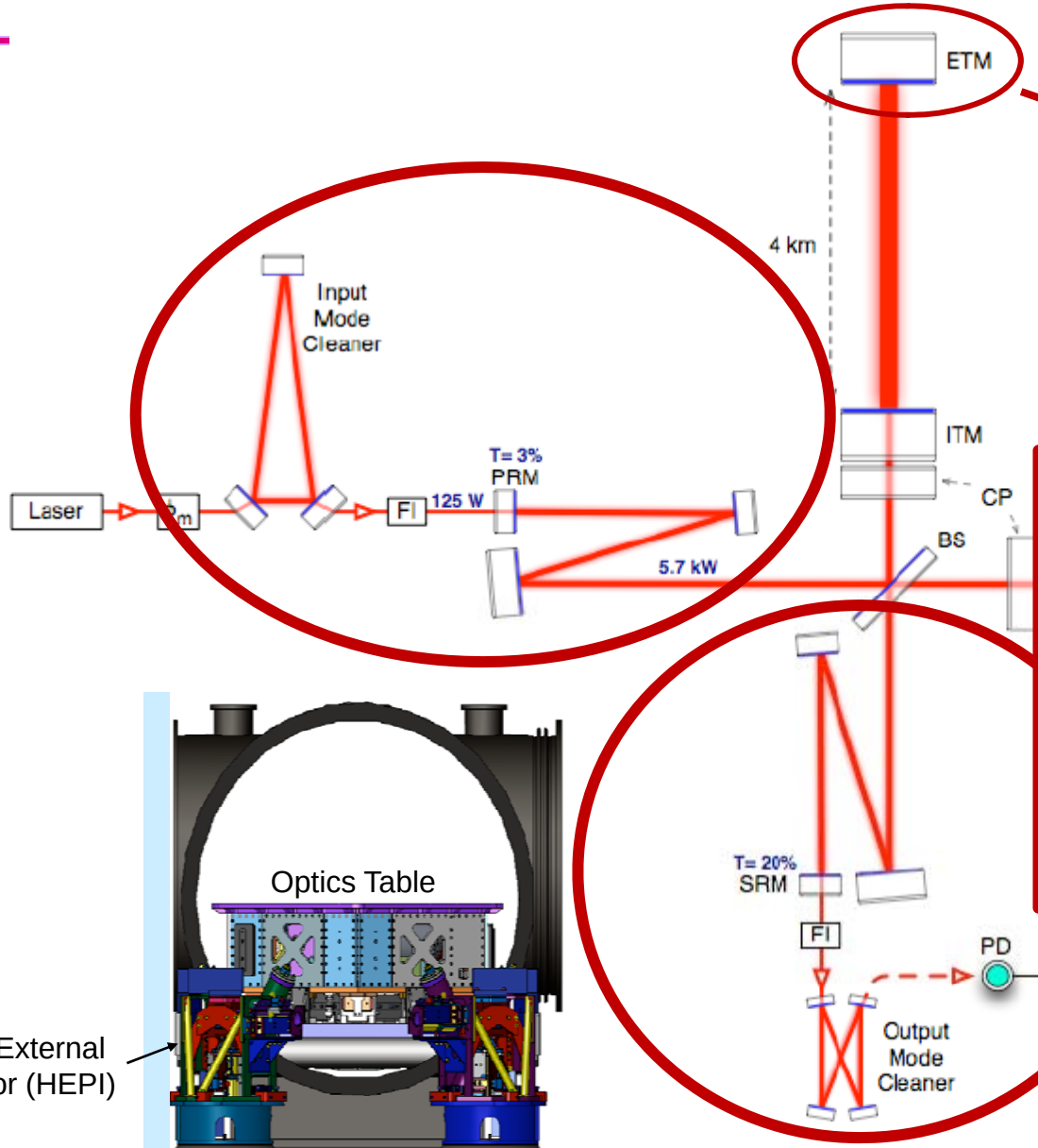
- Led by Peter Fritschel – fits in with Systems coordination role
- Contributions of designs and hardware from Australia – Jesper Munch and David McClelland leading
- Mostly in design phase, but with some electronics already in production, and some near-final prototypes (in eLIGO)





Seismic Isolation





Isolates suspensions and other in-vacuum Equipment from ground motion; Accepts control signals

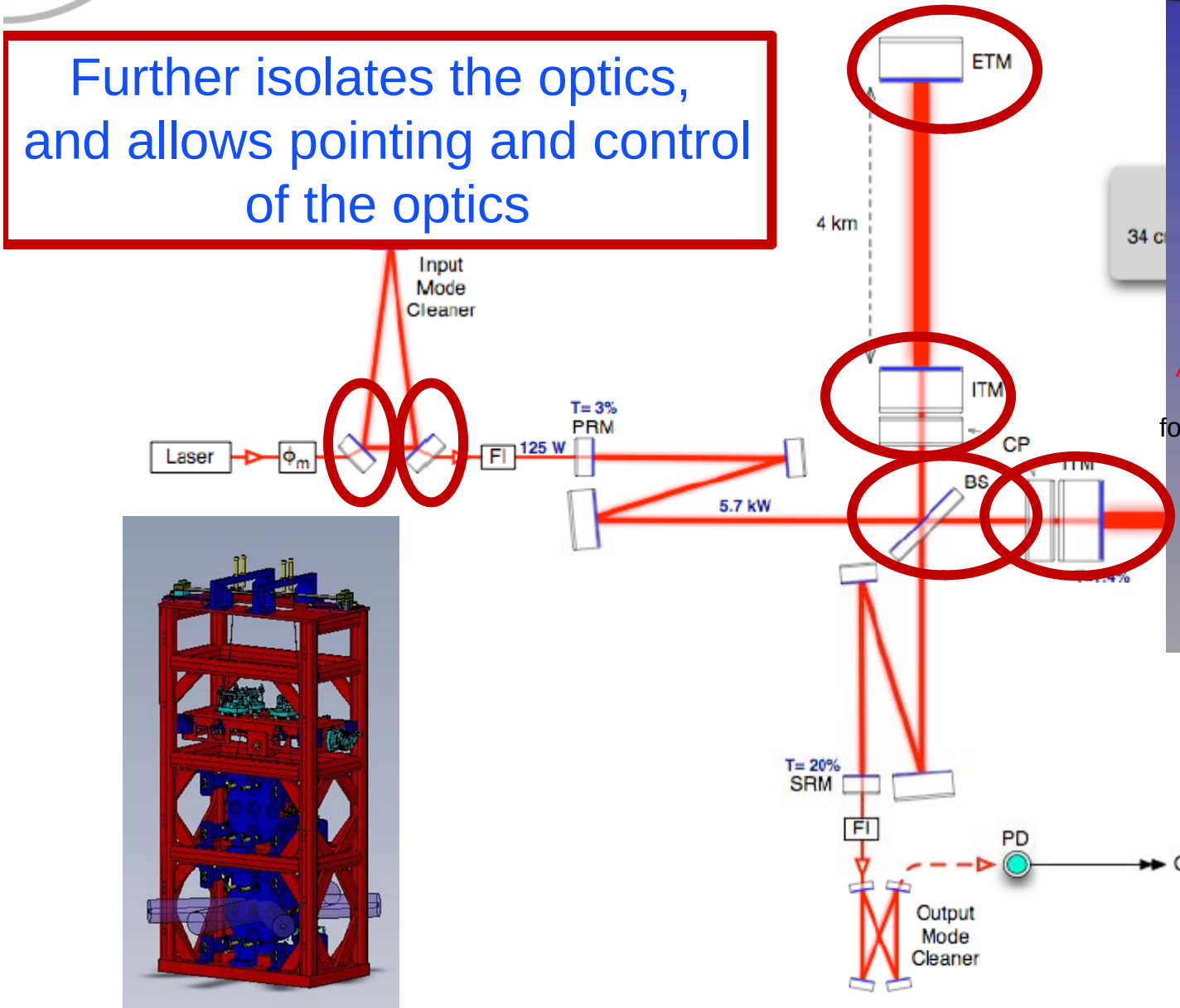
Hydraulic External Pre-Isolator (HEPI)

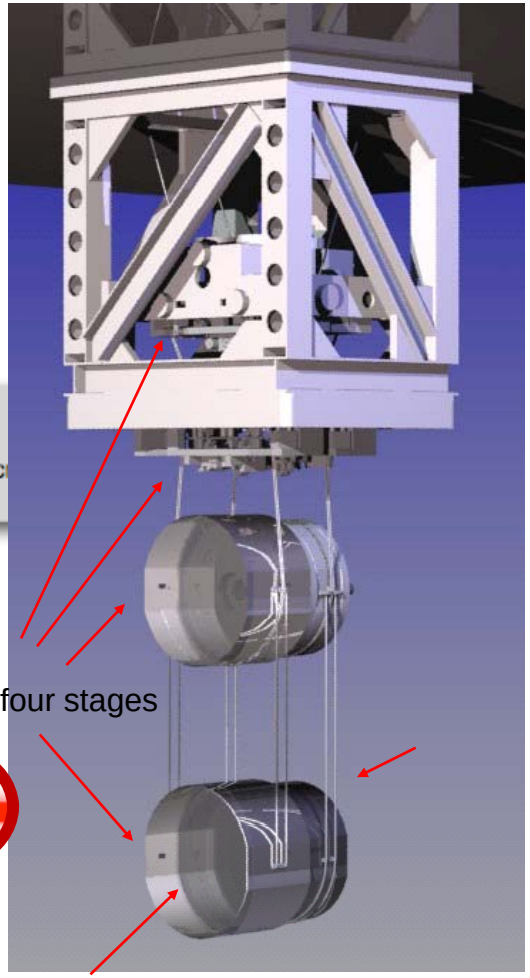
Seismic Isolation

- Led by Ken Mason, science lead Brian Lantz at Stanford
- A lot of equipment rolling in the doors, in fab at vendors
- Hydraulic Pre-Isolator (HEPI) already in at LLO, assembling for LHO
- HAM isolators successfully used in eLIGO
- LLO processing and assembling HAM isolators **NOW**

Suspensions (SUS)

Further isolates the optics, and allows pointing and control of the optics

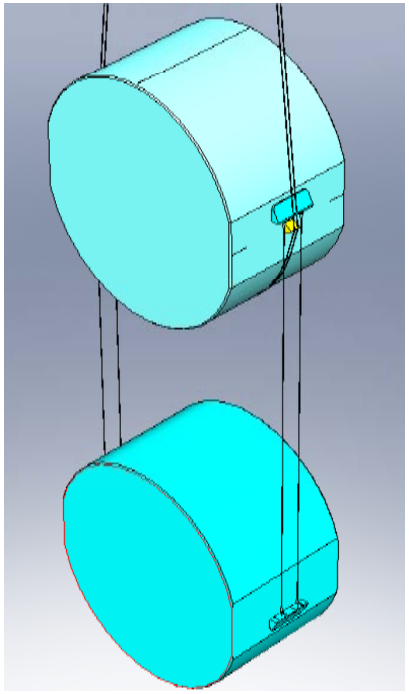




40 kg silica test mass

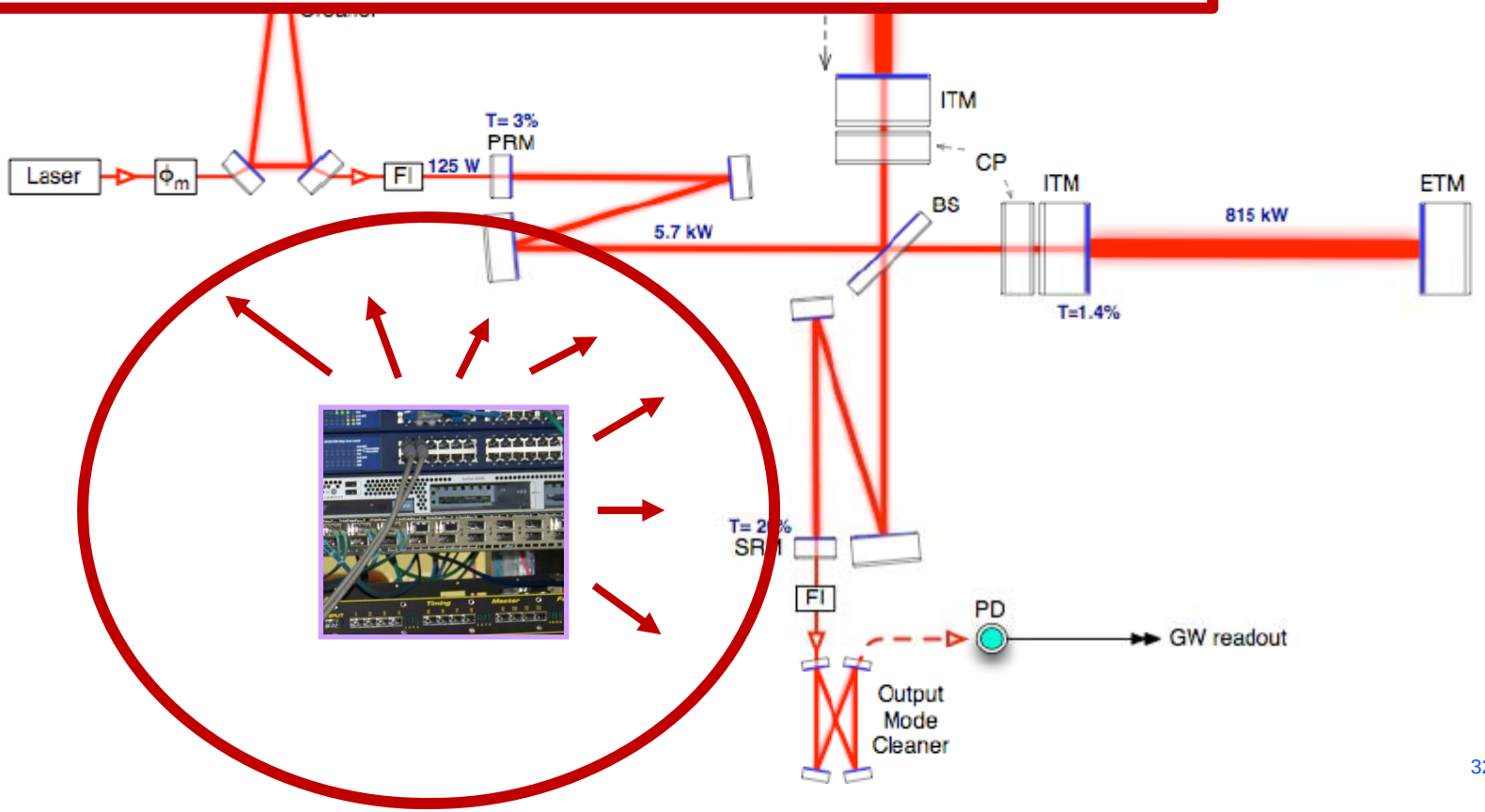
Suspensions (SUS)

- Norna Robertson leads; UK designed and contributed test mass suspensions, led by Ken Strain; US designs under Janeen Romie
- Test Mass suspensions use glass fibers to support 100lb test mass – reduces the thermal noise, introduces fun technical challenges
- Fabrication about complete on test mass suspensions, in cleaning and assembly
- Fabrication starting on many of the other suspension types



Data Acquisition and Control (DAQ)

The central electronic system that conditions and digitizes signals, processes them, sends out control signals, and sends the data for archiving



Data Acquisition and Control (DAQ)

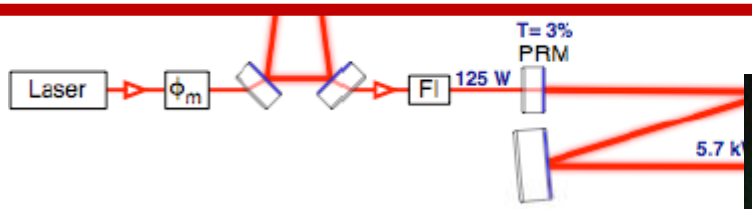
- Led by Rolf Bork, with teams at LLO, LHO, Caltech
  - » Timing design and delivery by Columbia, Szabi Marka leading
- Many of the aLIGO DAQ systems currently in use for eLIGO

- Equipment procurement starting up

Data and Computing System (DCS)

The data processing, archiving, and sharing
for the gravitational wave data
and the auxiliary signals used to 'clean' the data

Will be procured at the end of the project –
Best bang for the buck



What's in store for 2010?

- All subsystems will be deep into fabrication with a number of significant elements completed
  - » All Core optics will be polished, some coated
  - » All test mass suspensions assembled, some auxiliary sus. also
  - » All HAM chamber seismic systems fabricated, some assembled
  - » Some BSC (test mass) chamber seismic isolation systems assembled
  - » Initial DAQ systems networking and nodes complete to support the first integration testing
  - » First-needed vacuum equipment modifications will be ready
  - » Sensing and Control pre-lock stabilization – one unit to be ready

and…

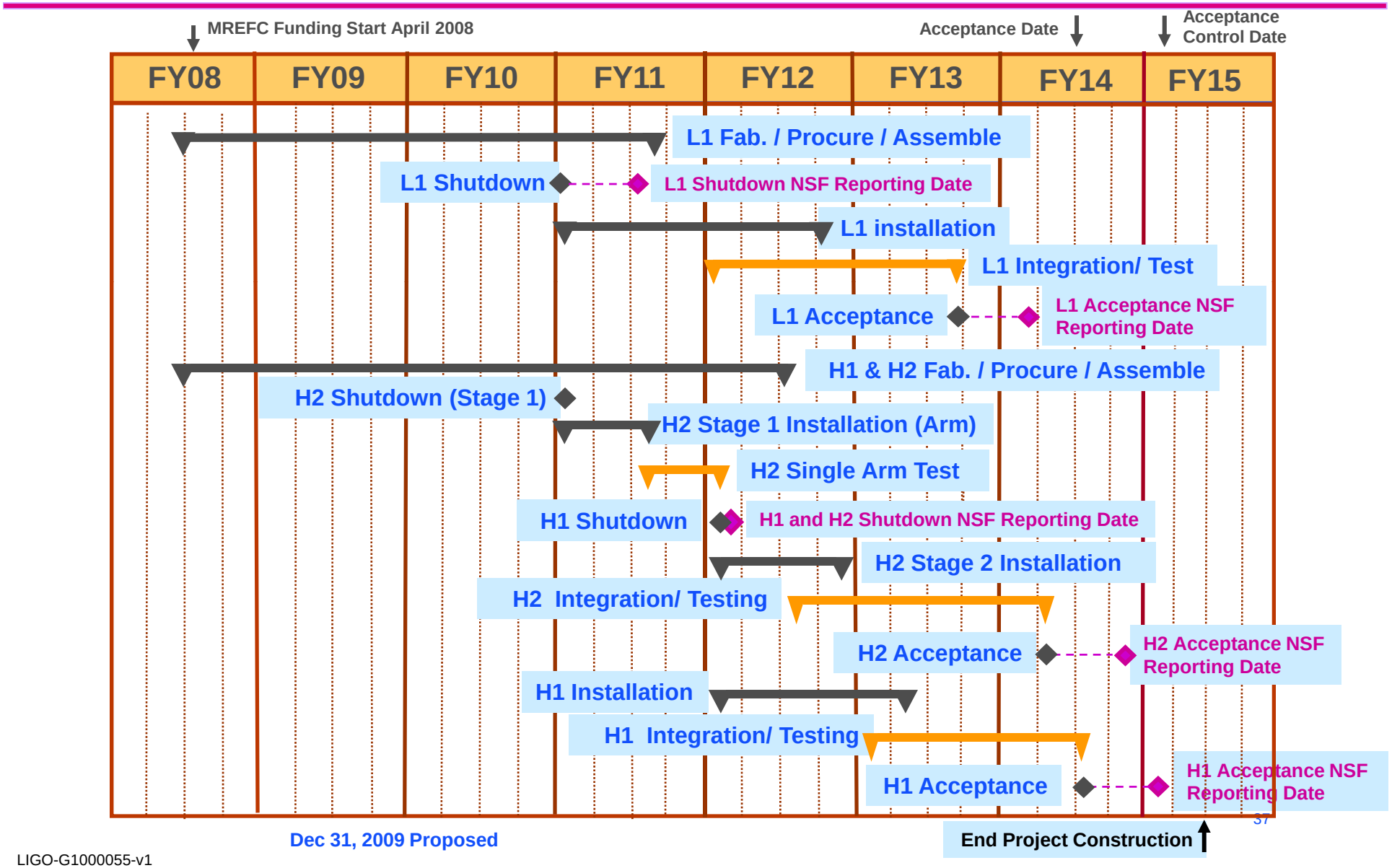
Shutdown of first interferometer site

Installation and Integration (INS)

- Install led by Carol Wilkinson, with site leaders Brian O'Reilly and Mike Landry; Integration led by Peter Fritschel
- As subsystems finish assembly and standalone test, they pass on to the Install/Integration activity –
  - » But the same people continue to work on the parts!
- Current activity is the planning – what needs to be done by when, what order of activity
- Will shut down observatories about the same time
  - » October-December 2010 – a bit less than a year from now!
- Will pursue one 4km arm interferometer at LHO, PSL and IO at LLO
  - » Partial installation with testing at both sites, followed by rest of install
- First thing is to remove initial LIGO and clean chambers
  - » Optics contamination under study, to know how to clean

Advanced LIGO Proposed Schedule Summary Cartoon

(Including selected NSF Reporting milestones for project contingency of 7 months)



At last, the Last Slide

- Advanced LIGO is coming along well
- We are keeping close to our planned schedule, and ahead of the NSF due dates
- Costs are ok, in some measure because the economy is soft
- Finding we need more people, and happy to have found a handful of very good new team members
- NSF is solidly behind the Project, and our funding is more sure than most things in life (and especially in this economy!)

- Please let me know if you have questions, concerns, or ideas on how we can do better – dhs@mit.edu

- Thank you for your contribution to the Project!